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Effects on soil temperature, moisture, and maize yield of cultivation with ridge and furrow mulching in the rainfed area of the Loess Plateau, China

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ABSTRACT

Field experiments were conducted from 2008 to 2010 in the Weibei Highlands of China to determine the effects of cultivation with ridge and furrow mulching on soil temperature, moisture, and maize (*Zea mays* L.) growth and yield. Ridges were covered with plastic film in all the treatments. Different furrow treatments were mulched with plastic film (PE film) (PP), biodegradable film (PB), maize straw (PS), and liquid film (PL). For the control (CK), ridges were covered with plastic film and the furrows received no mulching. Compared with CK, the soil water storage and soil temperature in furrow were significantly higher with the PP and PB treatments 0–60 days after planting (DAP), evapotranspiration was significantly higher at 60–90 DAP, but significantly lower at 120–140 DAP. The PS treatment had the highest soil water storage and the lowest temperature, while evapotranspiration was significantly lower at 0–60 DAP but significantly higher at 120–140 DAP, when compared with CK. Soil water storage and temperature were slightly higher with the PL treatment during the maize-growing season when compared with CK, but there were no significant differences in evapotranspiration. The three-year mean maize yields with PP, PB, and PS were significantly increased by 13.0%, 13.8%, and 15.0%, respectively, while water use efficiency increased by 9.8%, 10.2%, and 11.6%, compared with CK. Net income and input/output was highest with PS, and the three-year average net income increased by 1888.0 Chinese yuan (CNY) ha^{-1}, compared with the control. Soil moisture and temperature conditions were improved, while the maize yield and net income were increased, when ridges were covered with plastic film and the furrows were mulched with straw. Therefore, this treatment may be considered the most efficient for maize production in the rainfed area of the Loess Plateau, China.

1. Introduction

Plastic-covered ridge and furrow rainwater harvesting systems (PRFRHS) consist of alternate parallel ridges and furrows on flat land, where the ridge is covered with plastic film and the crop is planted in the furrows. This method is one of the most efficient technical applications for maximizing rainfall use (Han et al., 2004). PRFRHS can improve the crop root zone soil moisture availability by collecting water from light rain, which significantly increases the crop yield and water use efficiency. It also reduces unproductive evaporation and promotes rainfall infiltration (Carter and Miller, 1991; Li et al., 2000, 2001; Xie et al., 2005; Zhang et al., 2007). Many studies of PRFRHS have been reported. Zhu et al. (2002) showed that spring wheat yields were increased by 17.6–72.8% with PRFRHS, while the water use efficiency was increased by 3.05 kg ha^{-1} mm^{-1}, compared with conventional flat cultivation (without ridges and mulches) in the Dingxi semi-arid area, Gansu, China. Li et al. (2006) found that, compared with flat cultivation using mulches, ridge and furrow rainfall harvesting cultivation could improve the soil moisture and heat condition, which significantly increased maize yields in the Longdong dryland, China. Ren et al. (2008) also showed that with different rainfall levels (230, 340, and 440 mm), ridge and furrow rainfall harvesting led to increases in the spring maize yield of 82.8%, 43.4%, and 11.2% compared with conventional flat cultivation, while the water use efficiency was increased by 77.4%, 43.1%, and 9.5%, respectively. These studies were focused on the application of plastic-covered ridges and bare furrows. Compared with conventional flat cultivation, plastic-covered ridges and bare furrows can increase the rainfall use efficiency and crop yield to some extent (Tian et al., 2003; Wang et al., 2009). However, rainfall is low in the Loess Plateau rainfed area of China and there is a high rate of evaporation (Li et al., 2001; Kang et al., 2001). The

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utilization of limited rainfall and the increase in water use efficiency is limited with bare furrows and there is still considerable potential for further improvements in crop production levels.

Furrow mulching with PRFRHS might further improve the rainfall use efficiency by inhibiting soil evaporation. Though the research on plastic film mulched with both ridges and furrows has been involved (Li et al., 2001; Zhang et al., 2006; Ma et al., 2008; Liu et al., 2009; Zhou et al., 2009), these studies were mainly concentrated in arid regions that received 200–300 mm of annual rainfall. The planting patterns mostly consisted of alternating large ridge and small ridge mulched with plastic film, and a single row of maize that was planted in furrows. It had a significant effect on water harvesting, improved soil temperature, increased crop yields and produced a greater economic benefit. These results are valuable for rainfed maize production in the arid region, but this planting pattern may not be entirely suitable for crop production in the semi-humid area. Moreover, plastic film was a major mulching material in the past study on PRFRHS, and there are fewer results on application of degradable materials in RFRHS.

Therefore, the present study was mainly aimed at rainfed agriculture region where received 500–600 mm of annual rainfall in Loess Plateau of China. In particular, we wanted to compensate for low temperature during the maize seedling stage and for the drought that occurs during the growing season in this region. We aimed to improve the dryland maize growth environment and increase the efficiency of rainwater utilization, by combining rainwater harvesting on ridges with water conservation in furrows. Ridges were covered with plastic film in all treatments, but the furrow was mulched with different treatments, i.e., plastic film, biodegradable film, liquid film, and maize straw. For the control, the ridges were covered with plastic film and the furrows remained bare. The objectives of the present study were to: (1) investigate the effects on soil temperature, water use, and maize growth and yield of different ridge and furrow mulching cultivation, to provide a scientific basis for improved rainwater harvesting cultivation; (2) compare and analyze the economic benefit and input–output ratio, and single out an optimum ridge and furrow mulching water harvesting pattern for maize cultivation in the semiarid Loess Plateau region.

2. Materials and methods

2.1. Site description

Experiments were conducted between 2008 and 2010 at the Heyang Dryland Farming Experimental Station, Shaanxi Province, China (35°15′N, 110°18′E; 910 m above sea level). The mean annual temperature was 10.5 °C. The total annual sunshine was 2528 h and the frost-free period was 169–180 days. The annual mean precipitation was 550 mm, with 65% falling between July and September. Rainfall during the experimental period was measured using an automatic weather station (WS-STD1, England) at the experimental site. Monthly precipitation distributions during the experimental period are shown in Fig. 1. The total precipitation for 2008, 2009, and 2010 was 469.6, 499.6, and 515.2 mm, while the precipitation during the maize-growing season was 330.3, 389.1, and 431.0 mm, respectively.

The soil at the experimental site was a silt loam with a pH of 8.1, with a field water holding capacity (FWHC) of 21.6% and a permanent wilting point (PWP) of 9.8%, the soil at the experimental site was a silt loam with a pH of 8.1. In the 0–20 cm soil layer, the organic matter, total N, P, and K were 10.9 g kg^{-1}, 0.8 g kg^{-1}, 0.6 g kg^{-1}, and 7.1 g kg^{-1}, respectively, while the available N, P, and K were 74.4 mg kg^{-1}, 23.2 mg kg^{-1}, and 135.8 mg kg^{-1}. In 2008, the site was planted with maize prior to the experiment.

2.2. Experimental design and field management

PRFRHS were prepared by shaping the soil surface into alternate ridges and furrows. Ridges (60 cm wide, and 15 cm high) were covered with plastic film in all the treatments, while different furrows (60 cm wide) were mulched with plastic film (PP), biodegradable film (PB), maize straw (PS), liquid film (PL), or left uncovered (CK). A double row of maize was planted in furrows (Fig. 2). Each treatment had three replicates and each plot was 8.1 m long and 3.6 m wide, with a complete randomized arrangement.

Thirty days before planting, ridges were banked up with soil on the site and a base fertilizer containing 150 kg N ha^{-1}, 150 kg P_2O_5 ha^{-1}, and 150 kg K_2O ha^{-1}, was spread evenly over the furrow and plowed into the soil layer. Mulching was then applied to the soil surface. Ridges were covered with plastic film (LLDPE/LDPE blend resin, the expected life span is 1–2 years; 80 cm wide and 0.008 mm thick, obtained from the Shanxi Yuncheng Plastic Plant, Shanxi, China), while the furrows of the PP and PB plots were mulched with plastic film and biodegradable film (composed of polyethylene and starch, the degradation process begins after 60 days; supplied by Shaanxi Huayu Biological High-tech Co. Ltd., Shaanxi, China), respectively. Maize straw was cut into 15 cm long segments and uniformly applied at a rate of 9000 kg ha^{-1} in furrows with the PS treatment (Cai et al., 2011). Liquid film (Biochemical fulvic acid as raw material, the expected life span is 40 d; purchased from Beijing Jinshanghe Bio-tech Co. Ltd., Beijing, China) was diluted 1:5 (product: water) and sprayed on the soil surface

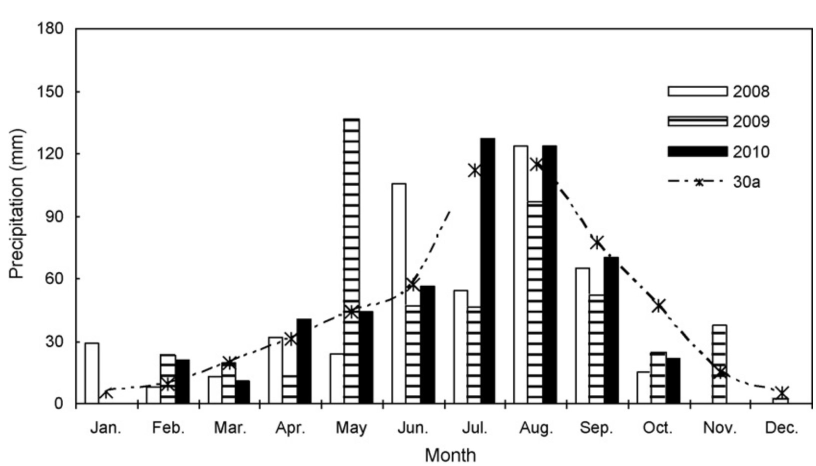

Fig. 1. Monthly precipitation distribution from 2008 to 2010 and the 30 year average (30a) at the experimental site.